PROCEEDINGS OF SCIENCE

PoS(HCP2009)097

Prospects for the Discovery of a Standard Model Higgs Boson Produced via Vector Boson Fusion and Decaying to $b\bar{b}$ in Association with a Central Photon

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In this work we discuss the potential for detecting the Standard Model Higgs boson decaying to a $b\bar{b}$ pair requiring that it is produced through the Vector Boson Fusion mechanism with an associated central photon at the Large Hadron Collider (LHC). The presence of this photon decreases the cross section by approximately a factor of α_{em} however it introduces several advantages. With a simple rectangular cut analysis we achieve a significance ~ 3.8 using ALPGEN interfaced with HERWIG. We include the expected b-jet efficiency and fake rates and other detector acceptance cuts in order to obtain a more realistic result.

XXth Hadron Collider Physics Symposium
November 16 – 20, 2009
Evian, France

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1. Motivation

A primary goal of the LHC is to understand the Electroweak Symmetry Breaking (EWSB) mechanism. In the Standard Model (SM), EWSB is described by the Higgs mechanism that includes a scalar Higgs Boson. The largest branching ratio decay for a SM Higgs in the 114-160 GeV/c^2 mass range is $h \rightarrow b\bar{b}$. The analysis of this decay would provide sensitivity to the $h \rightarrow b\bar{b}$ coupling and other properties of the Higgs such as spin and CP. The largest SM Higgs production mechanism, gluon-fusion, is inaccessible for $h \rightarrow b\bar{b}$ detection due to its overwhelming background, therefore focus is turned to the second largest production mode, Vector-Boson-Fusion (VBF). However, defining an efficient trigger that also suppresses the large QCD background within the allowable trigger rate is very challenging. One possible solution proposed by [1] is to require an associated central photon to the VBF production. Although requiring an associated photon decreases the cross section by approximately a factor of α_{em}, it introduces several advantages [1] such as providing a clean and efficient trigger, reducing the gluonic QCD background since gluons do not radiate photons or decreasing the combinatoric background, $b\bar{b} + jj + \gamma$, because coherence effects inhibit the production of central photons.

In this study, we investigate the effect originating from hadronization, showering, the Underlying Event (UE) model, and jet performance on the discovery potential.

2. Signal and Background

The signal and background 4-vector samples used for this analysis were generated using ALPGEN [2]. The hadronization, showering, UE, and decays were performed using HERWIG [3]. The signal branching fraction was determined using HDECAY [4]. The primary background is inclusive $b\bar{b}$ pairs associated with multiple jets and a photon. In addition, QCD multijets with an associated photon are considered. The relevant cross sections are shown in Table 1.

3. Jet Reconstruction

To perform a more realistic analysis, we have implemented jet reconstruction using the particles after hadronization and showering as the jet components. We have tested the SISCone with 0.4 and 0.7 cone radius and AntiKt algorithms with 0.4 and 0.6 aggregation distances [5]. We studied five quantities of the jet reconstruction, they are: efficiency of individual jets, the jet pair efficiency as a function of the initial partons distance, the transverse energy linearity, the transverse energy resolution and the jet multiplicity after reconstruction. Considering all these criteria, the AntiKt algorithm with 0.6 aggregation parameter is the best choice for our analysis.

$\sigma(h\gamma jj)$	$69.74\ (pb)$
BR($h \rightarrow b\bar{b}$)	0.731
$\sigma \times BR$	$50.98\ (pb)$

	Parton #	$\sigma(pb)$	MLM ε (%)	$\sigma'(pb)$
bb+$n$parton+γ	1	1088	42	457
	2	658	36	237
$n$parton+γ	3	45789	20	9158
	4	17595	18	3167

Table 1: Left: Signal cross-section and branching fraction for a 115 GeV/c^2 Higgs mass. Right: Background cross-sections, matching efficiencies, and the effective cross-sections.

Events 100 fb^{-1}	m_h(115 GeV/c^2)	bb+2jets+γ	4jets+γ
All	5095 ± 16	23693000 ± 15000	310630000 ± 190000
$p_T^{\gamma} > 30$ GeV/c	2292 ± 11	8047300 ± 8900	108730000 ± 110000
# Jets ≥ 4	1619 ± 9	4408100 ± 6600	78087000 ± 94000
$p_T^{vj1} > 53$ GeV/c	1292 ± 8	2239900 ± 4700	43736000 ± 70000
$p_T^{vj2} > 27$ GeV/c	1088 ± 8	1588200 ± 3900	32094000 ± 60000
$M_{vj1,vj2} > 855$ GeV/c^2	560 ± 5	237000 ± 1500	4385000 ± 22000
$\lvert\eta_{vj1} - \eta_{vj2}\rvert > 3.85$	550 ± 5	223200 ± 1500	3873000 ± 21000
2 B-jets	151 ± 3	24420 ± 490	1600 ± 400
$p_T^{bj1} > 53$ GeV/c	142 ± 3	17360 ± 410	1190 ± 300
$p_T^{bj2} > 21$ GeV/c	139 ± 3	15710 ± 390	1160 ± 290
$\lvert\eta_{bj1} - \eta_{bj2}\rvert < 1.45$	129 ± 3	9960 ± 310	1160 ± 290
$\eta_{bj1} \times \eta_{bj2} > -0.3$	125 ± 3	9480 ± 300	820 ± 200
Central Jet Veto	110 ± 2	2480 ± 160	520 ± 130
$\lvert M_h - M_{bj1,bj2}\rvert < 11.5$ GeV/c^2	91 ± 2	400 ± 62	87 ± 22

Table 2: Expected number of events per 100 fb^{-1} for a 115 GeV/c^2 SM Higgs mass and the two main background samples at each step of the selection process ($vj1$ and $vj2$ represent the VBF jet candidates).

4. Results

We require the following selection criteria to accept an event: a photon with $p_T > 30$ GeV/c (motivated by the expected trigger) and four or more jets in the event. We identify the best VBF jets candidates by using a likelihood selector based on the geometrical properties of the VBF quarks. Additionally, we make some requirements on their transverse momenta, invariant mass, and the geometrical separation between the two VBF jets. We identify b-jets using truth information and a 60% b-tagging efficiency was applied. Similarly, c-jets and light jets were assigned 1/10 and 1/200 fake b-jet rates, respectively. Finally, once the VBF and b-jets were identified a veto on events with any remaining central jets, $|\eta| < 3.2$, with a $p_T > 20$ GeV/c was applied. Results of the selection cuts are shown in Table 2. Considering all the backgrounds we achieve a significance $S/\sqrt{S+B} \sim 3.8$ with 100 fb^{-1} accumulated data for a 115 GeV/c^2 SM Higgs mass. This sensitivity is comparable to results anticipated from $W/Zh(\rightarrow b\bar{b})$ [6] and when combined with VBF $h(\rightarrow b\bar{b}) + \gamma$ could enable the observation of a light SM Higgs decaying to $b\bar{b}$ with 50fb^{-1} of LHC data.

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